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ScienceDirect

Energy Procedia 97 (2016) 342 – 347

Energy Procedia

European Geosciences Union General Assembly 2016, EGU
Division Energy, Resources & Environment, ERE

Measurement of the $scCO_2$ storage ratio for the CO_2 reservoir rocks in Korea

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Abstract

Based on the lab experiments, the average $scCO_2$ storage ratio of the Janggi conglomerate was calculated at 31.2 %, which can be used to evaluate the feasibility of the Janggi basin as a $scCO_2$ storage site in Korea. Assuming that the average radius of the CO_2 storage formations is 250 m and the average thickness of the formations under 800 m in depth is 50 m, the $scCO_2$ storage capacity of the Janggi basin is larger than 400,000 tons, demonstrating that the Janggi basin has a great potential for use as a pilot scale test site for the CO_2 storage.

Peer-review under responsibility of the organizing committee of the General Assembly of the European Geosciences Union (EGU)

Keywords: CO_2 sequestration; CO_2 storage capacity; CO_2 storage ratio; Janggi basin; the $scCO_2$ reservoir

1. Introduction

South Korea is ranked 6th among the OECD countries for greenhouse gas emissions, with a total of 6 billion tons of greenhouse gases emitted annually, as a result, South Korea's participation in compulsory CO_2 reduction is inevitable in the post-Kyoto Protocol world [1]. Therefore, the CO_2 sequestration in Korea should proceed so as to reduce emission of CO_2 and concentration of CO_2 in the atmosphere. Among the various geological sequestration methods, the aquifer sequestration and carbonate mineralization methods are considered to be most suitable for Korea because domestic onshore oil and gas fields or halite layers are rarely present. Currently in Korea, several studies have

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Peer-review under responsibility of the organizing committee of the General Assembly of the European Geosciences Union (EGU)
doi:10.1016/j.egypro.2016.10.015

progressed in the selection of the CO_2 storage sites. Aquifer sequestration technology is one of the most efficient ways decreasing CO_2, and several domestic onshore sedimentary basins in Korea have potential as CO_2 sequestration sites. Among them, the Janggi basin is currently being evaluated as the most optimal CO_2 storage site in Korea [2, 3, 4].

The $scCO_2$ storage ratio (%) for a CO_2 reservoir is one of the most important factors in estimating the CO_2 storage capacity for geological formations and thus for selecting an optimal CO_2 storage site [5, 6]. The $scCO_2$ storage ratio is the fraction of the $scCO_2$ amount occupying pore spaces after the $scCO_2$ injection, and it can be calculated from the amount of $scCO_2$ that has been introduced into the pore spaces of the storage rock, replacing water [5]. From the $scCO_2$ storage ratio, the CO_2 storage capacity for the specific formation can also be calculated by volume of the stratum, average porosity and density of the $scCO_2$ [7, 8, 9]. The $scCO_2$ storage ratio and the CO_2 storage capacity for the reservoir rock in Korea have never been measured even in a laboratory. This study presents a quantitative investigation of the $scCO_2$ storage ratio under the CO_2 sequestration conditions to find out a successful subsurface CO_2 sequestration site in Korea. Laboratory experiments were performed to measure the amount of the $scCO_2$ replacing water in the pore spaces of the Janggi sandstones and conglomerates, which are classified as available CO_2 storage rocks in Korea. The feasibility of the Janggi sandstones and conglomerates as CO_2 storage strata in Korea was also evaluated according to the $scCO_2$ storage ratio measured in the experiments.

2. Experimental methods

2.1. Preparation of the conglomerate and sandstone cores

The Janggi basin is a Miocene sedimentary basin in southeastern Korea, an area which consists of small blocks such as the Guryongpo, Ocheon, Noeseongsan and Youngamri basins. Among them, the Noeseongsan and Youngamri blocks are available as CO_2 geological storage sites [2]. In particular, the Noeseongsan block is considered the most promising storage formation because it is deeper than the Youngamri block (it is possible to store CO_2 at below 800 m in depth) and also has stable cap rocks. In 2015, four sites in the Janggi basin were drilled by KIGAM (Korea Institute of Geoscience and Mineral Resources), and continuous drill cores to 1,200 m in depth were collected at each site. Fig. 1 shows a geological map around the two drilling sites (JG-1 and JG-4) and their well logging data.

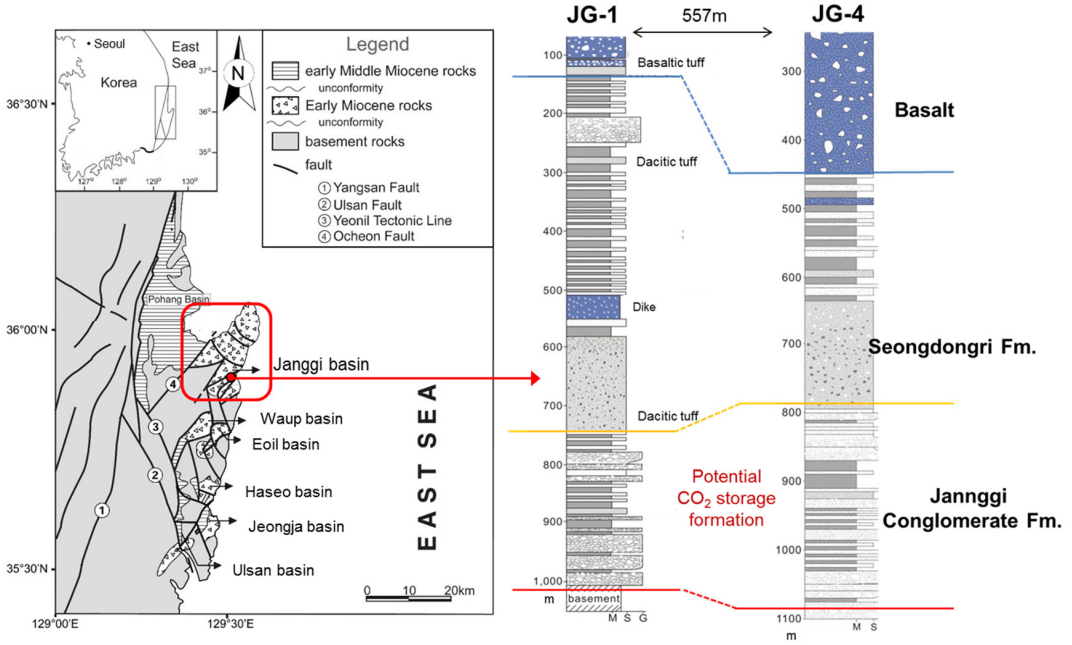

Fig. 1. The geological map around the drilling well locations (●) and well logging data for the rock cores used in the experiments.

A total of 7 consolidated cylindrical sandstone and conglomerate cores (4.2 cm in diameter; 6 - 7 cm in length of each) acquired at two sites (JG-1 and JG-4) were used for the experiment to measure the $scCO_2$ storage ratio after the $scCO_2$ injection.

2.2. Measurement of the $scCO_2$ storage ratio for the conglomerate and sandstone cores

Laboratory experiments were performed to measure the amount of the $scCO_2$, replacing water in the pore spaces of the Janggi sandstones and conglomerates, which are classified as available CO_2 storage rocks in Korea. The sandstone and conglomerate cores were cut (4.2 cm in diameter and 6 - 7 cm in length) and their surfaces were polished. A high pressure cell with two packing layers was developed to measure the amount of the $scCO_2$ stored in the pore spaces of each core after the $scCO_2$ injection. The difficulty with measuring residual $scCO_2$ in the pore spaces of the rock core is with the leakage of the $scCO_2$ at the boundary between the cell wall and the rock core. The high pressurized cell contains two different walls, with the inner wall being composed of a thick rubber layer. The rock core and the cell wall are in tight contact with the rubber inner layer when the pressure difference between the inner and outer walls of the cell increases due to pressurized water, which is injected into the outer part of the cell. In the case of this cell, the core and the core holder are held completely through the 200 bar of water between the outer cell wall and rubber layer. It is possible to cut off the bypass of groundwater through the boundary between the core surface and the cell wall, allowing the $scCO_2$ (or groundwater) to flow only through the sandstone core inside. Fig. 2 shows the photographs of the high pressurized cell and the schematic diagram for the cross section of the cell used in the experiment.

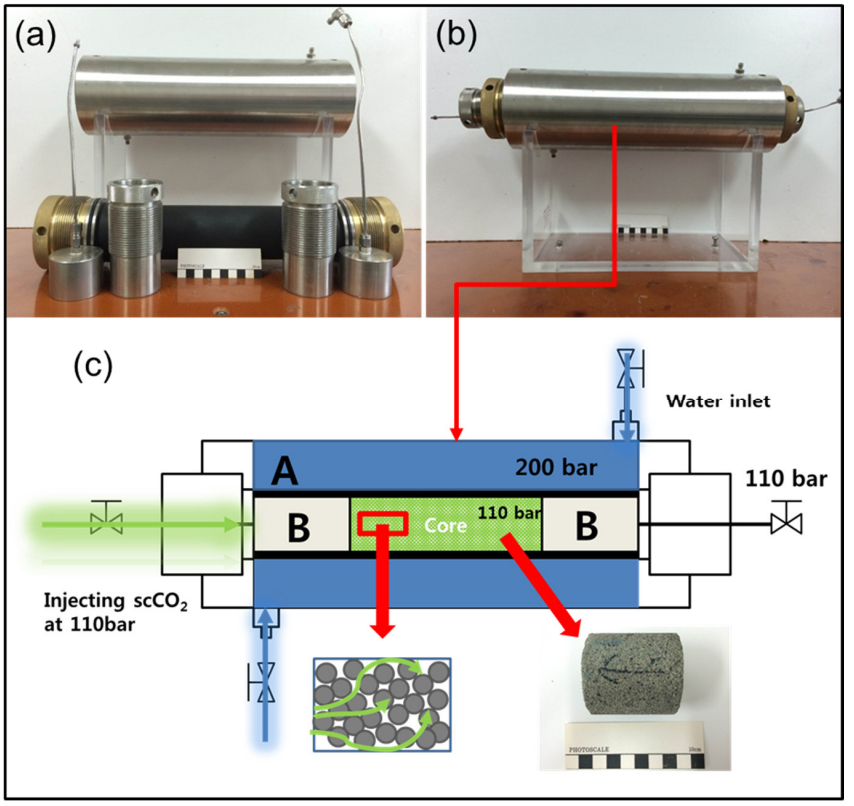

Fig. 2. Photographs of the high pressurized cell (a and b) and its cross-sectional schematic (c) used in the experiments.

For the experiment, each core was dried for 2 days at the 50 ºC in an oven, followed by measuring the mass of the dried core with a precision balance. The dried core was fixed in a high pressurized stainless steel cell. For the experiments, groundwater was sampled from two wells (450 m in depth) near the drilling site of JG-1 and JG-4. The pH and the chemical composition of groundwater are shown in Table 1. Because of the high contents of Na^+ and Cl^-, groundwater is considered to be affected by the marine transgression.

Table 1. The chemical composition and pH of groundwater used in the experiment.

	pH	Ion concentration (mg/L)										
		Fe^{2+}	Si^{4+}	Al^{3+}	Mg^{2+}	K^+	Ca^{2+}	Na^+	F^-	SO_4^{2-}	Cl^-	NO_3^-
JG-1	8.39	0.00	14.31	0.00	2.74	2.91	3.13	327.20	4.36	3.63	145.21	3.10
JG-4	8.64	0.00	12.38	0.00	1.80	34.48	2.50	319.73	5.46	0.00	138.98	0.00

Groundwater was flushed through the core at 100 bar of the injection pressure for 3 pore volumes of the core to fully saturate the micro pores with groundwater. Then, the $scCO_2$ was injected into the influent of the cell to replace groundwater in the pore spaces of the core at 110 bar until the pressure of the pore water in the core reached to 110 bar, up from 100 bar. After more than 2 pore volumes of the $scCO_2$ was flushed out from the core (assuming the replacement of the $scCO_2$ was successfully done), the core mass was weighed to measure the amount of groundwater replaced by the $scCO_2$ in the rock core. The high pressurized stainless chamber (5 L of capacity) was connected to the effluent of the cell to consider the boundary condition of the reservoir rock when the $scCO_2$ was flushed out from the rock core in the experiment. The water in the pore would be compressed while the pore pressure increased due to the $scCO_2$ injection and the enough water and/or $scCO_2$ volume should be secured in the chamber for the replacement of the $scCO_2$ during the experiment. All of the high pressure cells were maintained at 50 ºC and 110 bar after the CO_2 injection to simulate the CO_2 storage conditions under the subsurface. Fig. 3 shows the procedure of the core experiment.

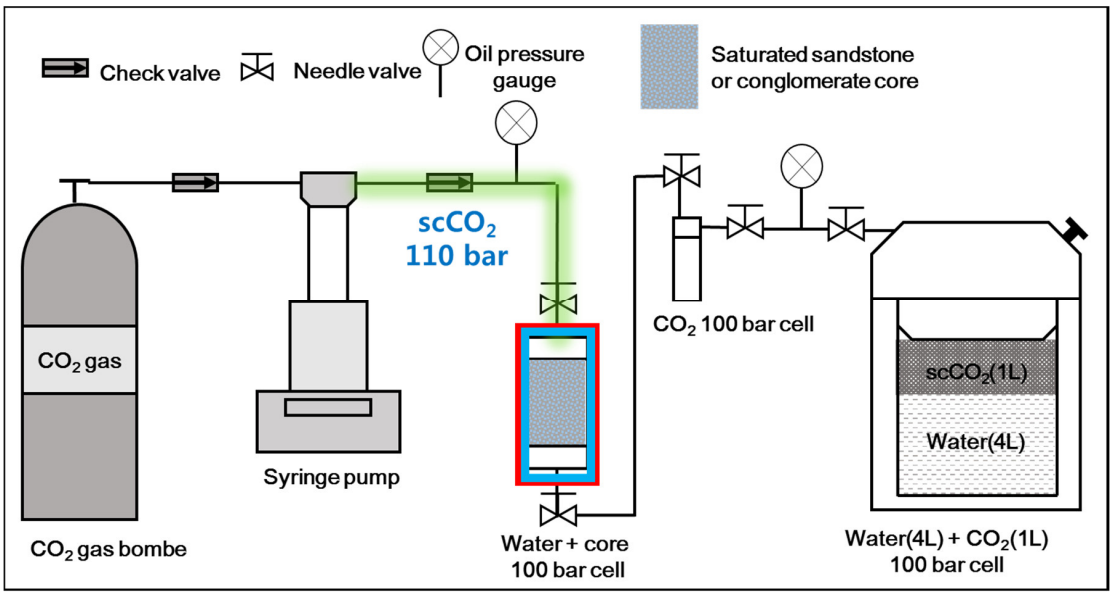

Fig. 3. The schematic process to measure the $scCO_2$ storage ratio of the rock core.

When the $scCO_2$ was injected, groundwater saturated in the void space of the sandstone was not fully replaced by the $scCO_2$ because of the interfacial tension difference (or wettability difference) between water and the $scCO_2$. Thus the amount of the $scCO_2$ that can be stored in the subsurface reservoir rock becomes smaller than the total void space of the rock. Before the CO_2 injection in the subsurface, the CO_2 storage capacity for the specific reservoir rock should be determined based on the real $scCO_2$ storage ratio. However, the studies related to the CO_2 storage capacity of the reservoir rock in Korea have not been performed yet. In this study, the CO_2 storage capacity of the conglomerate and the sandstone formations in the Janggi basin were estimated via Equation (1) with the volume of the stratum, the average porosity, the specific gravity of the $scCO_2$ and the storage ratio of $scCO_2$ [5, 6].

$$The\ storage\ capacity\ (ton) = \sum (V \times \varphi \times \rho \times \epsilon) \quad (1)$$

where V is volume of the conglomerate and the sandstone layers (estimated from the previous geological survey data), φ is the average porosity, ρ is the specific gravity of the $scCO_2$ and ε is the $scCO_2$ storage ratio. The feasibility of the Janggi basin as a CO_2 reservoir formation was evaluated based on the $scCO_2$ storage capacity.

3. Results and discussion

3.1. Measurement of the $scCO_2$ storage ratio for the conglomerate and sandstone cores

Results of the experiments to measure the $scCO_2$ storage ratio are shown in Table 2. From the experiment, the average $scCO_2$ storage ratio of the Janggi conglomerates was calculated as 31.2 %, which was 2.8 times higher than that of the sandstones, suggesting that these rocks have a great capability for storing CO_2 in the pore spaces.

Table 2. The $scCO_2$ storage ratio (%) of the conglomerates and sandstones.

Rock core name (depth: m)	Rock type	Porosity (%)	The $scCO_2$ storage ratio (%)	Average $scCO_2$ storage ratio (%)
JG1-163-2 (893.3)	Conglomerate	14.13	28.13	31.21
JG1-163-2 (893.5)	Conglomerate	13.67	18.22	
JG1-163-3 (893.4)	Conglomerate	15.65	41.54	
JG4-176-3 (936.5)	Conglomerate	12.97	38.90	
JG4-176-3 (936.7)	Conglomerate	15.74	29.25	
JG1-169-1 (931.9)	Sandstone	16.50	16.28	11.00
JG1-169-1 (932.1)	Sandstone	14.13	5.63	

3.2. Estimation of the $scCO_2$ capacity for two formations in the Janggi basin

In 2014, the Korean government created a plan for a few million tons of CO_2 injection at an onshore sedimentary basin, and the Janggi basin was considered the most promising basin for the CO_2 sequestration. As a preliminary feasibility study for the safety, more than a hundred thousand tons of CO_2 will be injected into a pilot scale test site in the Janggi basin, and from a storage capacity point of view, the feasibility of two reservoir formations mainly composed of conglomerates and sandstones was evaluated. Assuming from previous geological surveys and well logging data that the radius of each formation surface around the JG-1 and JG-4 sites is 250 m and the average thickness is 50 m for the conglomerate and the sandstone under 800 m in depth, the $scCO_2$ storage capacity of these two formations in the Janggi basin was calculated using Equation (1) [4]. The parameter values and the calculated capacity of the two formations are shown in Table 3.

Table 3. The $scCO_2$ storage capacity of two formations in the Janggi basin and parameter values used to calculate it.

Major rock type of the formation	The $scCO_2$ storage capacity (ton)	Volume of the formation (m^3)	Average porosity	*Specific gravity of the $scCO_2$	Average $scCO_2$ storage ratio
Conglomerate	295,468	50 m x 250 m x 250 m x 3.14	0.144	0.67	0.3121
Sandstone	110,646	50 m x 250 m x 250 m x 3.14	0.153	0.67	0.1100

* : at 100 bar and 50 °C from [10]

The calculated $scCO_2$ storage capacity for two formations in the Janggi basin was larger than 406,000 tons, suggesting that the Janggi basin has a great potential as a CO_2 injection testing site for a hundred thousand tons of CO_2 injection in Korea.

4. Conclusion

Laboratory scale experiments successfully demonstrated that the conglomerate and the sandstone of the Janggi basin have a $scCO_2$ storage ratio high enough for use as a CO_2 sequestration test site in Korea. When considering only the $scCO_2$ capacity, two formations consisting of the conglomerate and the sandstone in Janggi basin were suitable as the CO_2 geological storage sites in a pilot scale onshore CO_2 storage test where a hundred thousand tons of CO_2 were injected. The quantitative measurement of the $scCO_2$ storage ratio applied in this study can be used to determine the practicable CO_2 reservoir rock around the storage site based on CO_2 capacity and can also provide meaningful information for the future decisions regarding CO_2 injection sites. Results derived from this study are based on only the laboratory scale experiments, and a large scale pilot study should be performed for more realistic results prior to CO_2 injection in the real field.

5. Acknowledgements

This work was supported by the Korea CCS2020 R&D Center (KCRC) grant funded by the Korean Government (Ministry of Science, ICT & Future Planning)(NRF-2013-M1A8A1035830).

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